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Transactions on Environment, Energy and Earth Sciences
ISSN: 2960-1924, eISSN: 2960-2300 | Volume 3
GRET 2024

Impact of Climate Change on the Emergence and Decline of Ancient Civilizations-Historical Climate Reconstruction from Earth Science Perspectives

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Abstract. The impact of climate change on ancient civilizations is an important research topic. Ancient societies were extremely dependent on natural resources and climatic conditions due to their constraints, and climate fluctuations often had far-reaching impacts on agricultural production, resource management, and social stability of ancient civilizations. The aim of this paper is to investigate the impact of climate change on ancient civilizations using geoscientific reconstruction of historical climate. The study includes an analysis of the information provided by ice core data and sediments, and then describes how climate change affected ancient civilizations from different perspectives. In addition, the essay summarizes how modern geosciences and technology have provided useful tools for related research fields. Through historical climate reconstruction, this paper deepens the understanding of how historical climate change affected ancient civilizations and provides valuable lessons for other researchers to follow.

Keywords: Climate Change; Earth Science; Ancient Civilization; Impact; Agriculture.

1. Introduction

Numerous paleoclimatologists and archaeologists today are dedicated to exploring the effects of climate change on ancient civilizations [1-3]. Due to the dependence of ancient societies on natural resources and climatic conditions, fluctuations in climate could have a profound impact on agricultural production, resource management and social stability. The Classic Maya civilization was situated in the lowland areas of eastern Mexico and northern Central America, where the ancient inhabitants developed agricultural techniques adapted to fragile soils and constructed infrastructures to mitigate soil erosion and leaching [1]. In order to discover how the climate change of the Mayan civilization affected ancient societies and whether there is a relationship between the climate change of the Mayan civilization and the world's environment, the researchers chose to measure isotopes of carbonates or organic molecules and to study the climate variability of the North Atlantic Ocean. Based on the data from the study, it was found that the Mayan civilization experienced several serious droughts between the ninth and eleventh centuries AD. Although the Maya's management of water resources during the Early Classic was successful in addressing the droughts, it failed to prevent societal collapse or allow for the recovery of much of the Maya lowlands during the droughts of the ninth through eleventh centuries [1]. During the late Preclassic period, the Maya civilization experienced incidents of slash-and-burn agriculture and population growth, which resulted in anthropogenic environmental degradation [1]. At the same time, there were massive erosion and soil deposition events in the lakes and swamps [1, 4]. The environmental changes caused by the humid climate of the period could affected social stability and were a possible factor in social breakdown.

The aim of this essay is to analyze the impact of climate change on ancient civilizations from the perspective of earth sciences. Earth sciences could provide this study with analytical application tools for reconstructing historical climate and understanding the influence of climate change on ancient civilizations. This article generalizes the research methodologies used in other studies and analyzes how the research factors reveal that climate change affected ancient civilizations. In addition to this, the research focuses on the mechanisms of climate change, how climate change affects societies, and analyzes examples of how ancient civilizations responded to climate change. Finally, geoscience techniques will be used to model historical climatic conditions and detect environmental changes at ancient sites. The data is then integrated and analyzed to discover potential connection between climate change and the rise and fall of civilizations. Despite abundant research analyzing the association between climate change and ancient civilizations, there is a lack of overviews based on earth science perspectives. This article provides new perspectives for investigating the interactions between climate and ancient societies, systematically demonstrates how climate change affects the rise and fall of complex societies, and offers some workable tools for predicting climate change in today's societies

2. Historical climate reconstruction methods

2.1. Ice core data

Ice cores are cylinders of ice obtained by drilling polar ice caps or glaciers, currently most ice core records come from Antarctica and Greenland. Ice cores contain small bubbles inside, which can be used to measure past atmospheric gas concentrations directly by drilling the cores and analyzing the composition and isotope ratios of the gases enclosed in these small bubbles [5].

Oxygen isotopes of precipitation deposited in layered ice cores are widely used as paleoclimate proxies, particularly in studies focusing on localized temperatures at mid- to high latitudes and precipitation in the tropics [6]. Some researchers have used a reconstruction technique that could seamlessly integrate proxy information with climate models, which is based on data assimilation [6, 7]. At first, they created pseudo-proxy models using the Proxy System Model (PSM), which could transform climate signals such as temperature and precipitation into synthetic proxy time series. In the study, the water isotope fields of ECHAM5-wiso/iCAM5 and PSM were used to make a modeling of the pseudo-proxy ice core. Ice core PSMs could mimic the original signals of nature and take into account the uncertainties and analytical errors that are ultimately associated with the measurement of ice core data. Next, the researchers used a similar reconstruction framework to the pseudo-proxy for the real ice core isotope reconstruction. Differently, they reconstructed the real experimental framework using many new data reconstruction ensembles consisting only of ice cores, when reconstructing the real experimental framework. Then a posterior ensemble named grand was created. By using both pseudo-proxy reconstructions and a real-proxy experimental framework, this study makes predictions about the spatial and temporal scales of how ice cores could provide information about past climate and confirms that ice cores can reconstruct local measurements of temperature and atmospheric circulation [6].

Numerous studies are now focused on the Antarctic region and Greenland, where ice core data used in different studies have been able to reveal past temperature changes and climate fluctuations, providing valid basic data for reconstructing the climates of ancient civilizations [8].

2.2. Sediment analysis

Compared to other regions, the climate in the Arctic is increasing at an accelerated rate. Under these circumstances, glaciers are extremely sensitive to climate change. Signals generated by glaciers are transmitted to downstream lake sediments through changes in rock-flour production [9]. Components such as pollen and fossilized microsomes in the sediments of such lakes and oceans record changes in ancient environments and climates.

After the seismic survey of Lake Hajeren, the researchers extracted sediment cores from the innermost part of the basin and processed the acquired data using the RadExplore software package. The analyzed data revealed a uniform distribution of soft sediments in two sub-basins. The researchers performed a multi-proxy analysis of the sediments in the lake in order to accurately detect glacial activity. In reconstructing glacial activity, organic content is used as an inverse indicator of sediment in glacier-fed lakes. However, organic content in lakes is not only influenced by sediment, but is also related to redox-sensitive metal ratios. To overcome the limitation, the researchers used Dry Bulk

Density (DBD) to track variations in minerogenic lacustrine input and Principal Component Analysis (PCA) to help fingerprint glacial sediments. The discussion was categorized into non-glacial environmental variability and Holocene glacier variability, focusing on the characterization of sediments from various periods of glaciation [9].

The study of Lake Hajeren promoted the study of climate variability in the archipelago by scientists, and many studies are now analyzing and studying the sediments in conjunction with different disciplines. These sediments provide insights into the pattern of regional climate change and its impact on the surrounding environment.

3. Impact of climate change on ancient civilizations

Climate change has significantly influenced the trajectories of ancient civilizations, affecting their development, stability, and eventual decline. By altering environmental and social dynamics, climate change has impacted key areas such as agriculture, water resource management, social stability, urbanization, and infrastructure development. Understanding these impacts provides valuable insights into how past societies adapted to and were challenged by environmental changes.

3.1. Agricultural production

Agriculture was the backbone of many ancient civilizations, providing not only food but also the economic surplus necessary for societal development. Climate change affects agricultural production through changes in temperature, precipitation patterns, and seasonal cycles. These climatic factors directly influence soil moisture, crop growth rates, and harvest periods. For example, a rise in temperature could lead to drought conditions, while changes in precipitation could result in either flooding or insufficient water supply, both of which are detrimental to crop health and yields.

A notable example is ancient Egypt, which heavily relied on the seasonal flooding of the Nile River to irrigate its farmlands. These floods brought nutrient-rich silt that was crucial for agricultural productivity. However, variations in climate, such as prolonged droughts or irregular flooding patterns, disrupted this natural cycle, leading to periods of famine and social unrest. Moreover, climate change could lead to earlier crop growth, which could result in shorter growing periods [10]. The occurrence of certain extreme weather events could negatively affect vital plant growth stages, such as flowering and photosynthesis. In Egypt, yields of crops such as wheat, soybeans, and sugarcane decrease as temperatures rise. However, cotton and potato yields increase with higher temperatures. In addition to this, saltwater intrusion could directly affect agricultural productivity [10]. The increase in soil salinity due to evapotranspiration and saltwater intrusion due to sea level rise will deplete agricultural land in the Nile Delta [10].

Increasingly severe, frequent and longer-lasting heat waves, large-scale droughts, changes in river flows, and rampant plant pests and diseases could also have an influence on agricultural production. These disruptions not only threatened food security but also undermined the economic stability and political power of the state.

3.2. Water Management Resource

Water is a critical resource for any society, and ancient civilizations were no exception. Climate change impacts water resource availability by altering precipitation patterns, river flows, and groundwater levels. These changes pose challenges in managing water supply, particularly in regions prone to drought or flooding. Effective water management strategies were crucial for the survival of ancient societies, especially those in arid or semi-arid regions.

The ancient civilizations of the Andean region, such as the Inca, developed sophisticated water management systems to cope with the harsh and variable climate. The pre-Inca civilization, designed to improve the community's capability to adapt to the dry season, developed catchment interventions and established an infiltration system to sustain the local agricultural production. The local infiltration system consists of diversion channels, infiltration canals, infiltration slopes, springs and ponds [11]. It firstly distributed water resources through different ditches to increase the subsurface storage, and also created surface storage through the established ponds. The results of the relevant studies show that the water management system adopted by the Inca civilization could effectively store rainy season flows for agricultural production in the drought season [11].

These innovations enabled them to sustain agriculture in challenging environments, supporting large populations and complex societies. However, significant climatic shifts could overwhelm even the most advanced water management systems, leading to societal stress and collapse.

3.3. Social Stability and Migration

Climate-induced environmental changes can lead to resource scarcity, which in turn can cause social instability, conflict, and population displacement. When essential resources like food and water become scarce, competition intensifies, potentially leading to internal strife, societal fragmentation, or forced migration. Such conditions can destabilize governments, disrupt trade networks, and erode the social cohesion necessary for the maintenance of complex societies.

In ancient Mesopotamia, prolonged periods of drought have been linked to societal upheavals and migrations. The collapse of the Akkadian Empire around 2200 BCE, for example, has been associated with a severe drought that caused widespread crop failures, food shortages, and ultimately, the mass migration of people seeking more hospitable environments. Such demographic shifts could alter the cultural and political landscape of entire regions, leading to the rise of new powers or the disintegration of established ones.

3.4. Urbanization and Infrastructure

Climate-induced environmental changes can lead to resource scarcity, which in turn can cause social instability, conflict, and population displacement. When essential resources like food and water become scarce, competition intensifies, potentially leading to internal strife, societal fragmentation, or forced migration. Such conditions can destabilize governments, disrupt trade networks, and erode the social cohesion necessary for the maintenance of complex societies.

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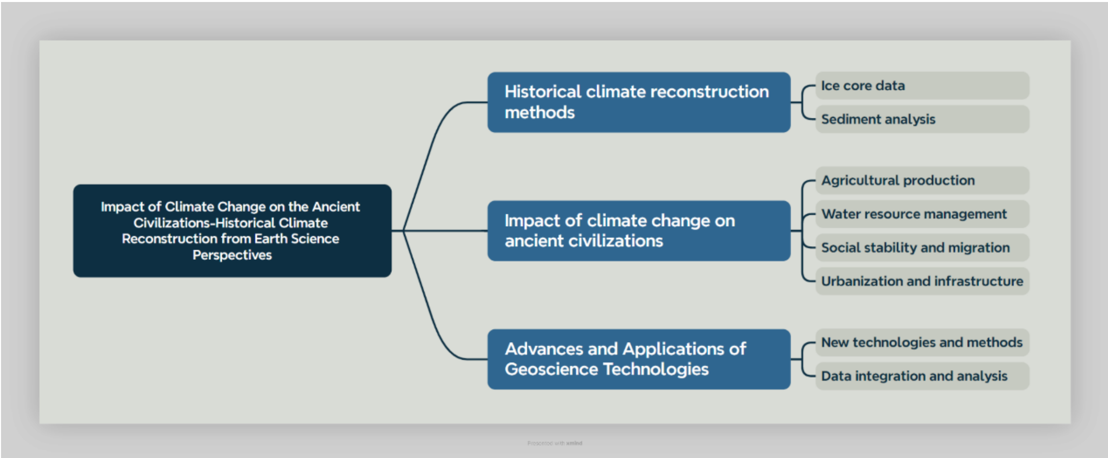

Fig. 1 Research mind maps

4. Advances and Application of Geoscience Technologies

The study of climate change and its impact on ancient civilizations has been greatly enhanced by advances in geoscience technologies. These technologies provide researchers with powerful tools for reconstructing past climates, analyzing environmental changes, and understanding their implications for human societies.

4.1. New Technologies and Methods

Climate Models and Simulations: Modern climate models allow scientists to simulate past climate conditions, providing a dynamic and detailed picture of how ancient environments may have looked. These models can incorporate data from various sources, such as ice cores, tree rings, and sediment layers, to reconstruct historical climate patterns. By simulating different climate scenarios, researchers can gain insights into how ancient civilizations might have experienced and responded to environmental changes.

Remote Sensing Technology: Remote sensing involves using satellite imagery and aerial photography to monitor and analyze changes in the Earth's surface. In archaeology, remote sensing can be used to detect and map ancient settlements, agricultural fields, and water management systems. It also helps in monitoring environmental changes around archaeological sites, offering high-resolution data on land use, vegetation, and hydrology. This technology provides archaeologists with a non-invasive way to explore large areas and uncover evidence of past human-environment interactions.

4.2. Date Integration and Analysis

Interdisciplinary Integration: Combining climate data with archaeological and historical data enables researchers to conduct comprehensive analyses of the complex interactions between humans and their environment. By integrating data from multiple sources—such as climate records, archaeological findings, and historical texts—researchers can build a more complete picture of how ancient societies were affected by climate change. This interdisciplinary approach allows for a deeper understanding of the resilience and adaptability of past civilizations.

Big Data Analysis: The advent of big data technologies has opened new avenues for analyzing large volumes of environmental and archaeological data. By using advanced data analytics, machine learning, and statistical methods, researchers can identify patterns and correlations that were previously undetectable. Big data analysis helps in discovering potential links between climate change and the rise and fall of civilizations, offering new insights into the factors that drive societal change.

5. Conclusion

This article provides an overview of the application of earth sciences to the study of the rise and fall of ancient civilizations, particularly how climate change impacted ancient societies. The study summarizes the environment in which ice core data and sediments were formed, and how researchers have used this material to obtain information about climate change. After gaining an understanding of how the material aids in research, an analysis of the different ways in which climate change impacted ancient civilizations is discussed. Eventually, it is concluded that advances in modern science and technology have provided more precise tools and methods for investigating ancient climates. Although modern science and technology have advanced rapidly and provided advanced instruments for research in specialties such as archaeology and earth sciences, the field still faces challenges such as data uncertainty and regional variability. In future research, the understanding of ancient climate change will be further deepened with advances in geoscience and technology, which will provide valuable insights and useful tools for modern societies to study and adapt to climate change.

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